Use of Elemental Analysis for Discrimination of Bristol Bay Sockeye Salmon Stocks

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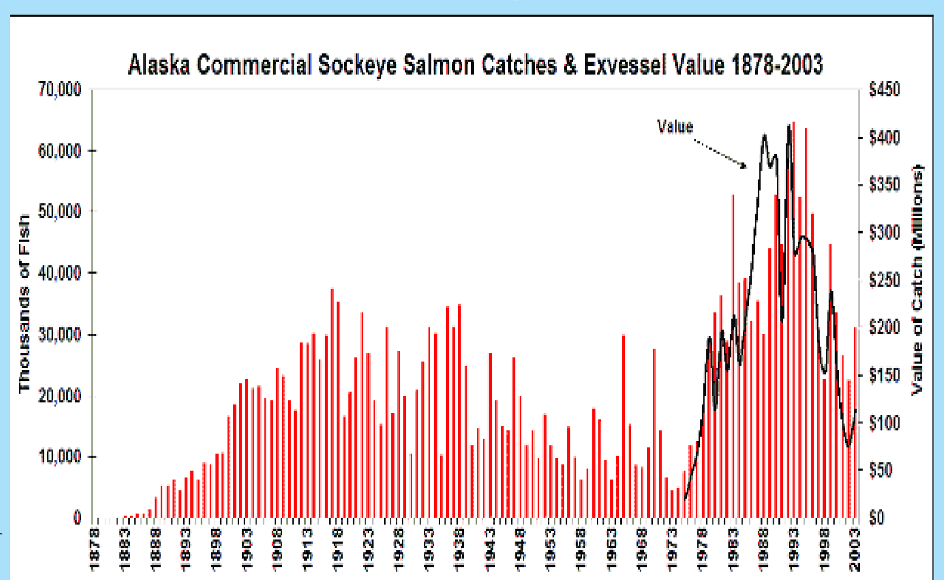
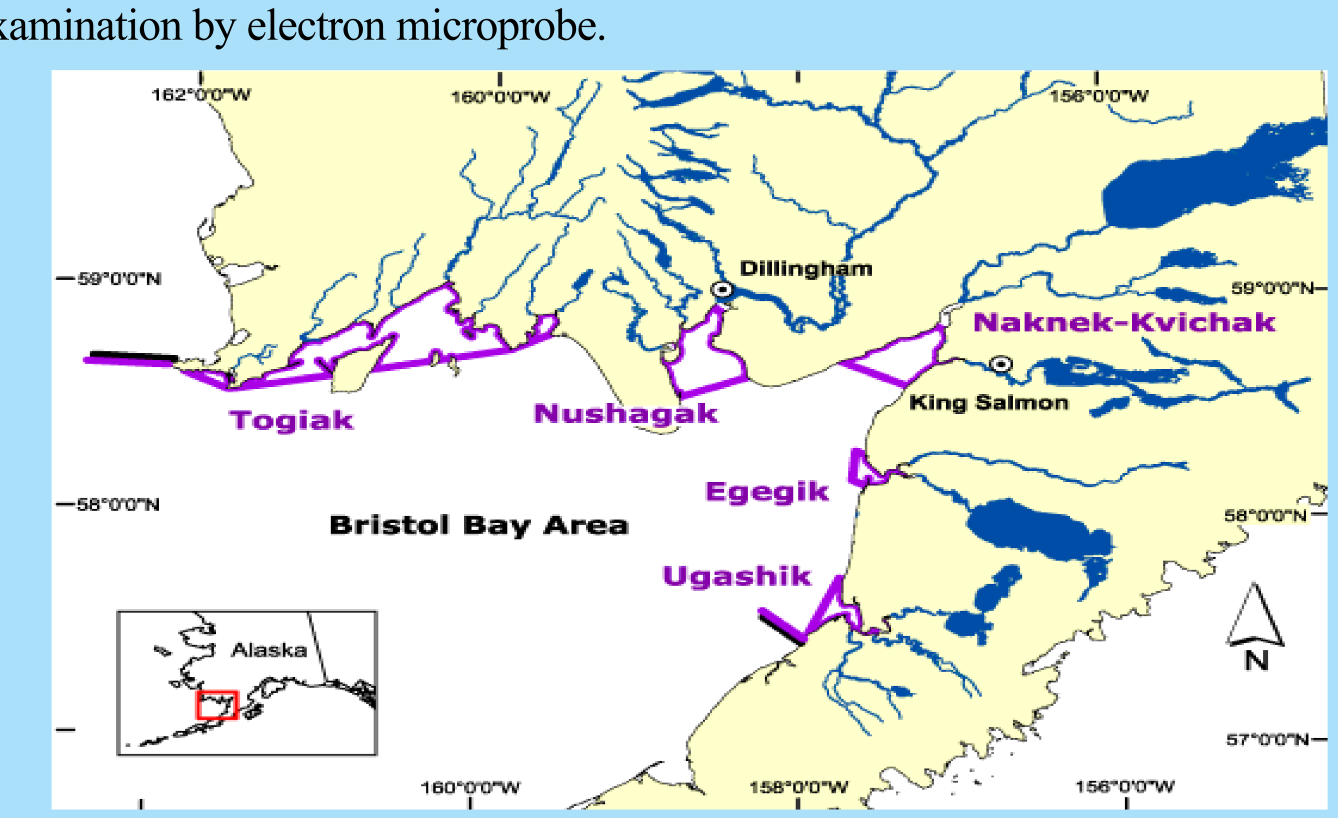
The largest harvest of sockeye salmon in the world occurs in the Bristol Bay area of southwestern Alaska where 10 million to more than 30 million sockeye salmon may be caught each year during a short, intensive fishery lasting only a few weeks. Most sockeye salmon are harvested with gillnets either drifted from a vessel or set with one end on the shore. Sockeye salmon are the preferred species for canning due to the rich orange red color of their flesh. Today, however, more than half of the sockeye salmon catch is sold frozen rather than canned. Canned sockeye salmon is marketed primarily in the United Kingdom and the United States while most frozen sockeye salmon is purchased by Japan. Sockeye salmon roe is also valuable. It is salted and marketed in Japan.

In recent years, below average returns of sockeye salmon to the Bristol Bay region have prompted state and federal agencies to declare the Bristol Bay region of Alaska an economic disaster area.
Specific mechanisms related to reduced Bristol Bay sockeye salmon production are unknown due to the lack of stock-specific information on early marine residence and sparse or outdated data on the life history of immature and maturing salmon as they travel the waters of the Bering Sea and North Pacific Ocean. To assess life history characteristics of Bristol Bay sockeye salmon stocks in the North Pacific Ocean and Bering Sea researchers must be able to identify salmon, at least by their country or continent of origin and ideally by region or watershed of origin when captured in various commercial fisheries and during research sampling. In this study, we examined and compared the concentrations of nine common elements found in the otoliths of juvenile sockeye salmon in Bristol Bay, Alaska. Our objective was to use differences in concentrations of naturally occurring elements in the otoliths to discriminate between three stocks of sockeye salmon. We assumed that the otolith concentrations would be reflective of the concentrations of those elements in the natal freshwater system.



Juvenile sockeye salmon (smolt) were collected from Kvichak, Egegik, and Ugashik River systems in eastern Bristol Bay as they emigrated to salt water from freshwater nursery lakes. The sockeye salmon smolt were frozen whole and sent to the National Marine Fisheries Service, Auke Bay Laboratory in Juneau, Alaska for laboratory analyses. The sagittae of 25 fish from each system were removed and prepared for examination using established techniques for grinding and polishing sagittae. The otoliths were then shipped to the Advanced Instrumentation Laboratory of the Department of Geology and Geophysics at the University of Alaska in Fairbanks, Alaska for examination by electron microprobe.

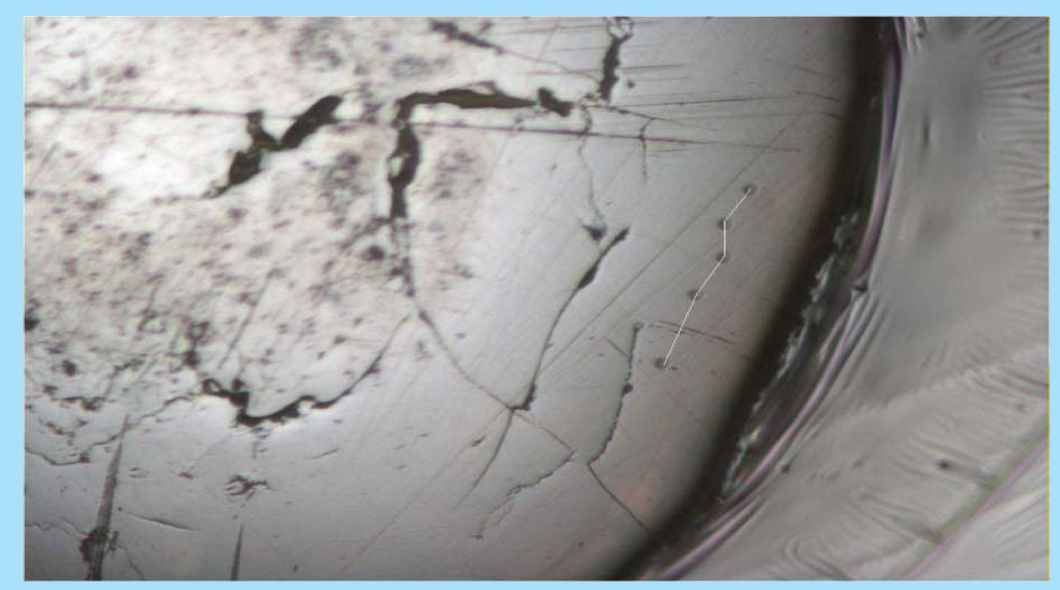


Elemental analysis of otoliths to determine origin utilized an electron micro-probe to detect small concentrations of naturally occurring elements within the otolith's crystalline microstructure. The microprobe detects a unique x-ray signature for each element and the mix of energy and wavelengths emitted from a sample can be used to quantify the amount and proportion of elements at the location of the beam. Element names, standards, count times, and detection limits are presented in the table below.

Standards, count times, detection limits and analytical errors of Cameca SX-50 electron microprobe.

Element	Standard	Count Time (Seconds)*	99% Detection Limit (Wt %)	Analytical Error (2s)
Na	Halite	90	0.02	0.03
Mg	Osumilite	90	0.02	0.01
P	Apetite	20	0.05	0.09
S	Anhydrite	20	0.04	0.06
Cl	Halite	46	0.03	0.02
K	Osumilite	46	0.02	0.02
Ca	Calcite	20	0.05	0.47
Fe	Hematite	180	0.04	0.03
Sr	Strontianite	180	0.04	0.03

For each otolith, five points were randomly selected for elemental analysis in an area on the otolith that was between 0.06 and 0.08 mm from the edge (dots on photograph at right). This area on the otolith corresponds to the time spent in freshwater lakes and their associated streams just before smoltification and emigration to salt water. Presumably, the concentrations of elements in this area are reflective of the characteristics of the lake system in which the juveniles reared.



	Freshwater System					
	Kvichak		Egegik		Ugashik	
Element	Mean (n=25)	s	Mean (n=23)	s	Mean (n=24)	s
Ca	38.998	0.788	38.922	0.865	38.789	0.846
K	0.108	0.021	0.083	0.024	0.103	0.029
Cl	0.023	0.007	0.022	0.007	0.028	0.023
P	0.176	0.042	0.131	0.049	0.120	0.043
S	0.040	0.013	0.044	0.013	0.051	0.015
Na	0.243	0.027	0.263	0.028	0.284	0.039
Mg	0.014	0.005	0.013	0.008	0.014	0.006
Sr	0.061	0.005	0.049	0.007	0.059	0.010
Fe	0.007	0.005	0.006	0.004	0.008	0.005

Elemental percents were then taken from the otoliths of fish collected in the fresh water systems (listied above). We determined that there was a significant ($p<0.05$) difference in otolith composition for six of the nine elements measured. Only the concentrations of Ca, Mg, and Fe were not significantly different between the three freshwater systems.

The table below presents a summary of a linear discriminate analysis classification (with cross-validation) of sockeye salmon by freshwater system based on elemental analysis.

Classified Group	Kvichak (n=23)	Egegik (n=25)	Ugashik (n=24)
Kvichak	21	4	5
Egegik	1	15	3
Ugashik	1	6	16
Proportion	0.913	0.600	0.667

Total
Number correctly classified = 52 Proportion correctly classified = 0.722

Discriminate analysis of the elemental data showed three distinct groups corresponding to the three river systems. The Kvichak river system sockeye (n=23) were grouped correctly 91.3 % of the time. The Ugashik river fish (n=24) had the next highest correct grouping with 70.8% followed by the Egegik river fish (n=25) at 68.0%. Overall 76.4% of the samples were correctly classified to the correct river system. When the discriminate analysis was run with cross-validation of the data the proportion of fish classified to the correct river system dropped to an average of 72.2%. An additional two Egegik fish and one Ugashik fish were misclassified. Classification of the Kvichak fish did not change. Cross-validation compensates for the optimistic apparent error rate which occurs when the data used to build the classification is the same data being classified.

The wave-length dispersive microprobe used in our study is adequate for detecting and discriminating most of the elements that were analyzed. The concentrations of elements in the otoliths of the juvenile salmon reflect not only their physical environment but also their own physiology at the point of sampling. Thus, the nutritional state of the fish, water temperature, and concentrations of the elements in prey and water source are important factors determining usefulness of various elements for stock separation. In our analysis we assumed that slight differences in the chemical make up of the rearing water coming from the lake systems as well as small differences in the metabolism of the fish would allow discrimination of stocks after they become mixed in the marine environment. Ideally the presence of a stable marker element, that is, one that is outstandingly different in abundance or unique to a particular system year after year would increase the accuracy of our ability to discriminate stocks. In addition, a baseline elemental analysis should be done on all stocks in the area each year. This would preclude uncharacterized stocks in a mixture being categorized in a known group.

Our results indicate that microprobe based elemental analysis of otoliths of sockeye salmon is potentially a good a tool to separate stocks in the eastern Bristol Bay area. The use of probe-based technology for discrimination of mixed sockeye salmon stocks in Bristol Bay, Alaska would be useful to managers and researchers who require stock specific information. Combined with the analysis of isotopes and genetic characters, as well as scales and parasites, elemental analysis can be an effective tool to discriminate between sockeye salmon stocks in Bristol Bay and the Gulf of Alaska.

Aknowledgments

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